Waveform Based Acoustic Emission Detection and Location of Matrix Cracking in Composites

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Introduction

The operation of damage mechanisms in a material or structure under load produces transient acoustic waves. These acoustic waves are known as acoustic emission (AE). In composites they can be caused by a variety of sources including matrix cracking, fiber breakage, and delamination. AE signals can be detected and analyzed to determine the location of the acoustic source by triangulation. Attempts are also made to analyze the signals to determine the type and severity of the damage mechanism. AE monitoring has been widely used for both laboratory studies of materials, and for testing the integrity of structures in the field.

In this work, an advanced, waveform based AE system was used in a study of transverse matrix cracking in cross-ply graphite/epoxy laminates. This AE system featured broad band, high fidelity sensors, and high capture rate digital acquisition and storage of acoustic signals. In addition, analysis techniques based on plate wave propagation models [1-4] were employed. These features provided superior source location and noise rejection capabilities.

For source location, the signal arrival times were determined by matching similar phase points in the digitized waveforms. This provided extremely accurate source location. Also, a novel four sensor arrangement was used on these narrow coupons instead of the one or two sensors used in previous coupon studies. This sensor arrangement improved the linear location accuracy providing excellent agreement with microscopy measurements of crack positions. The location resolution was also sufficient to provide, for the first time, a direct measurement that the cracks initiated at the specimen edge. The phase point matching method eliminated errors that result when threshold based arrival time determination methods are used on signals which suffer high attenuation and dispersion.

The plate wave propagation based analysis enabled the discrimination of crack generated AE signals from noise signals created by grip damage. Location results provided confirmation that the noise signals originated in the grip region. Grip tabs, which are often employed in AE tests to eliminate grip noise, were not required.

Measurements were made on specimen with different numbers of 90 degree plies. For specimens with three or more 90 degree plies together, there was an exact 1-1 correlation between AE crack signals and observed cracks. Ultrasonic backscatter scans and some destructive sectioning analysis showed that the cracks extended across the full width of the specimen. For specimens with only one or two 90 degree plies, the crack-type signals were significantly smaller in amplitude and there was not a good correlation to observed cracks. This was similar to previous results [5, 6]. In this case, however, ultrasonic and destructive sectioning analysis revealed that the cracks did not extend across the specimen. They initiated at the edge, but did not propagate any appreciable distance into the specimen. This explains the much smaller AE signal amplitudes and the difficulty in correlating these signals to actual cracks.

A recent study [5, 6] also investigated transverse matrix cracking in composite laminates with different numbers of 90 degree plies. Conventional AE amplitude measurements were correlated with cracks which were observed with penetrant enhanced radiography. For specimens with more than two 90 degree plies in a layer, there was excellent correlation (near 1-1) between large amplitude signals and observed cracks. However, AE location analysis was not used to provide confirmation that the matrix cracks were responsible for producing the large amplitude AE signals. For specimens with only one or two 90 degree plies, the correlation between large amplitude signals and cracks was poor. This result was not well understood, but is explained by the findings of this study.

In another study [3, 4], broad band sensors and a digital oscilloscope for waveform acquisition were used in addition to conventional (parameter based) AE measurements. Analysis based on wave propagation models in plate geometries allowed discrimination of signals generated by cracks from extraneous noise. Transverse matrix cracks were shown to preferentially generate extensional plate mode signals due to their in-plane source motion. Extraneous noise sources such as grip damage generated signals with large flexural mode components. These measurements provided the basis for the technique used in this work. However, waveform capture rate limitations prevented digital acquisition of all signals during the tests and only a single lay-up was tested.

Many other previous research efforts [for examples, see references contained in 5] have attempted to differentiate damage mechanisms in composites using conventional, parameter based, AE measurements. The majority of this work has focused on analysis of AE signal amplitude distributions. The theory is that different source mechanisms should generate different amplitude signals. However, the claims as to which source mechanism generates which amplitude signal have been conflicting. Few results have been confirmed by direct observations of damage mechanisms that created a particular signal. Also, wave propagation effects, including attenuation and dispersion, on the measured signal amplitude have been ignored in this approach.

Other methods are also used for studying transverse matrix cracking including penetrant enhanced radiography, edge replicas, and optical microscopy. These methods require that the mechanical test be paused for measurements at load intervals. This significantly slows the test procedure, particularly when the specimen must be removed from the test machine for the measurements. This can lead to problems with alignment, and specimen damage during regripping, and concerns about low cycle fatigue effects.

Experiment

Tensile coupon specimens (2.54 cm. wide by 27.94 cm. long) of AS4/3502 were tested under stroke control loading (0.127 mm/minute). Because grip damage noise was eliminated by waveform analysis, grip tabs were unnecessary. Six different cross-ply laminates were tested. The stacking sequences were [0_n, 90_n, 0_n] where n ranged from one to six. Thus, the samples varied in thickness from 3 to 18 plies. Rather than a single sensor at either end of the specimen, four broadband sensors (Digital Wave B1000) were used. At either end of the specimen gage length, a pair of sensors were positioned. The outer edge of each 6.35 mm. diameter sensor was aligned with the edge of the specimen. The motivation for this sensor array arrangement was the determination of the initiation site of the crack. Not only could the linear location along the length of the specimen be determined, but lateral location information was also obtained.

The signals were amplified 20 dB by wide band preamps (Digital Wave PA2400G) and then input into a digital acoustic emission analysis system (Digital Wave F4000). Additional system gain was applied, depending on the specimen thickness. Thicker specimens generated signals of larger amplitude. The additional system gain ranged from as little as 6 dB for the thickest specimen to 18 dB for the nine ply specimen (n=3). For the three and six ply laminates, the gain was significantly increased with the preamp gain increased to 40 dB and the system gain set as high as 18 dB in attempts to capture the much smaller amplitude signals from the partial cracks not propagating across the specimen. The maximum digitization sampling frequency of 25 MHz was used to provide the most accurate location results. Location was performed using cursor based, phase point matching, arrival time determination.

Results and Discussion

For the laminates with n = 3 or larger, there was an exact 1-1 correlation between crack-type AE signals and cracks observed with microscopy. Extraneous noise signals, which located outside the sensor gage length and were caused by grip damage or specimen slippage, were also detected. These were eliminated based on plate waveform analysis. Figure 1 shows typical waveforms from a crack signal which contains high frequency extensional mode components, and a low frequency flexural mode noise signal. Excellent crack location accuracy, as compared to the microscopy measurements, was obtained. Analysis of the AE data from the four sensors provided direct confirmation that the cracks initiated at one of the specimen edges. The sensor pair located on the same edge as the crack initiation site provided the most accurate crack location results. The average of the absolute value of the difference in crack locations from AE and microscopy was 3.2 mm. for a nominal sensor gage length of 152 mm. The amplitude of the signals was proportional to the thickness of the specimen, with larger numbers of 90 degree plies through which the crack propagated producing larger amplitude signals.

For the thin laminates (n = 1 or 2), the cracks were not always successfully detected. Those that were produced much smaller amplitude signals. Ultrasonic backscatter scans and destructive sectioning microscopy analysis showed that the cracks, which were visible at the specimen edge, did not extend into the interior of the specimen. This difference in crack initiation and growth explains the much smaller amplitude signals and the difficulty in detecting these cracks.

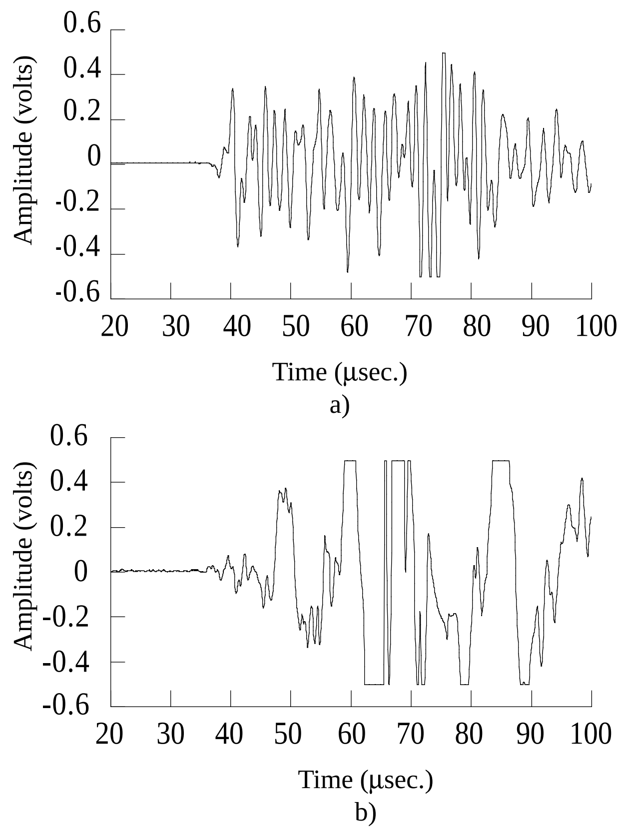

Figure 1 Typical signals caused by a) transverse matrix crack and b) grip slippage or damage

References

[1] Gorman, M. R., "Plate Wave Acoustic Emission," Journal of the Acoustical Society of America, Vol. 90, 1990, pp. 358-364.

[2] Gorman, M. R., and W. H. Prosser, "AE Source Orientation by Plate Wave Analysis," Journal of Acoustic Emission, Vol. 9, 1991, pp. 283-288.

[3] M. R. Gorman and S. M. Ziola, "Plate Waves Produced by Transverse Matrix Cracking," Ultrasonics **29** (1991) pp. 245-251.

[4] M. R. Gorman and S. M. Ziola, "Acoustical Detection of Transverse Cracking in a Crossply Composite," Proceedings of AECM-3, Paris (1989), pp. 286-297.

[5] J. P. Favre and J. C. Laizet, "Amplitude and Counts per Event Analysis of Acoustic Emission Generated by Transverse Cracking of Cross-Ply CFRP," Composites Science and Technology **36** (1989) pp. 27-43.

[6] J. P. Favre and J. C. Laizet, "Acoustic Analysis of the Accumulation of Cracks in CFRP Cross-Ply Composites Under Tensile Loading," Proceedings of AECM-3, Paris (1989), pp. 278-285.